

International Journal of Modern Physics A  
 © World Scientific Publishing Company

## Pentaquark searches at FOCUS

Kevin Stenson\*

*Department of Physics, University of Colorado, Campus Box 390  
 Boulder, CO 80309, USA*

We find no evidence for high-energy photoproduction of pentaquarks at 1540 MeV/ $c^2$ , 1862 MeV/ $c^2$ , or 3099 MeV/ $c^2$  using decay modes  $pK_S^0$ ,  $\Xi^- \pi^-$ , and  $D^{(*)-} p$ , respectively.

### 1. Introduction

A 4–7  $\sigma$  significant pentaquark with a mass of  $\sim 1540$  MeV/ $c^2$  decaying to  $pK_S^0$  or  $nK^+$  has been reported by ten experiments<sup>1–10</sup>. Combining the mass measurements of these experiments we find  $M = 1533.6 \pm 1.2$  MeV/ $c^2$ . The  $\chi^2/dof$  for this averaging is 38.2/9 giving a confidence level of  $1.6 \times 10^{-5}$ , a 5.2  $\sigma$  problem. Pentaquarks with two strange quarks<sup>11</sup> and with a charm quark<sup>12</sup> have also been reported.

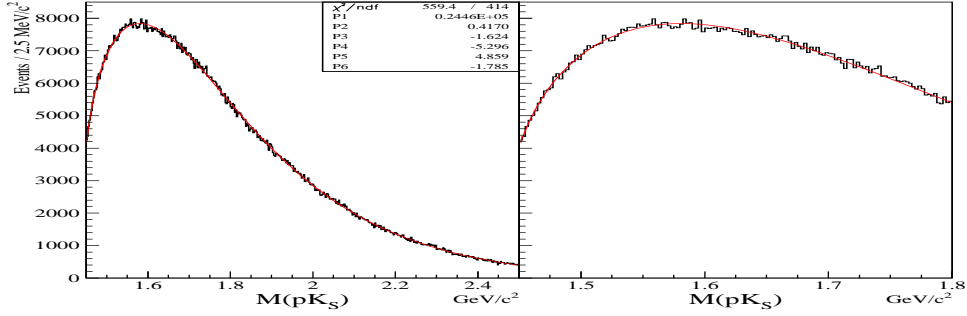
FOCUS ran during the 1996–7 fixed-target run at Fermilab. A photon beam from brehmsstrahlung of a 300 GeV electron and positron beam impacts BeO targets. 16 silicon strip planes provide vertexing and tracking. Charged particles are tracked and momentum analyzed as they pass through up to two dipole magnets and up to five sets of multiwire proportional chambers. Three Čerenkov counters, two EM calorimeters, and two muon detectors identify particles. A hadronic trigger requiring  $\sim 25$  GeV of energy passed 7 billion events for reconstruction. Thus, these events are well above threshold for pentaquark production. Charge conjugates are assumed for these analyses and all pentaquarks are assumed to decay strongly.

### 2. Search for $\Theta(1540)^+ \rightarrow pK_S^0$

We search for  $\Theta(1540)^+ \rightarrow pK_S^0$  and measure the production relative to two similar decays,  $K^*(892)^+ \rightarrow K_S^0 \pi^+$  and  $\Sigma(1385)^\pm \rightarrow \Lambda^0 \pi^\pm$ . The data is from events with a reconstructed  $K_S^0 \rightarrow \pi^+ \pi^-$  or  $\Lambda^0 \rightarrow p \pi^-$ <sup>13</sup>. Selecting vee candidates within 2.5  $\sigma$  of the nominal mass we obtain  $63 \times 10^6$   $K_S^0$  ( $8 \times 10^6$   $\Lambda^0$ ) candidates with 92% (96%) purity. The remaining good quality tracks must form a good vertex (CL > 1%). The proton candidate must pass stringent Čerenkov ID cuts, reducing the misidentification rate to  $\sim 0$ . The  $K^*(892)^-$  and  $\Sigma(1385)^\pm$  are fit with a simple Breit-Wigner plus background of  $aq^b \exp(cq + dq^2 + eq^3 + fq^4)$  where  $q$  is the energy release. We find  $(8.29 \pm 0.01) \times 10^6$   $K^*(892)^-$ ,  $(92 \pm 2) \times 10^3$   $\Sigma(1385)^+$ , and  $(146 \pm 3) \times 10^3$   $\Sigma(1385)^-$

\*on behalf of the FOCUS Collaboration (<http://www-focus.fnal.gov/>)

2 Kevin Stenson

Fig. 1. Fit to  $M(pK_S^0)$  in search for  $\Theta(1540)^+ \rightarrow pK_S^0$ .

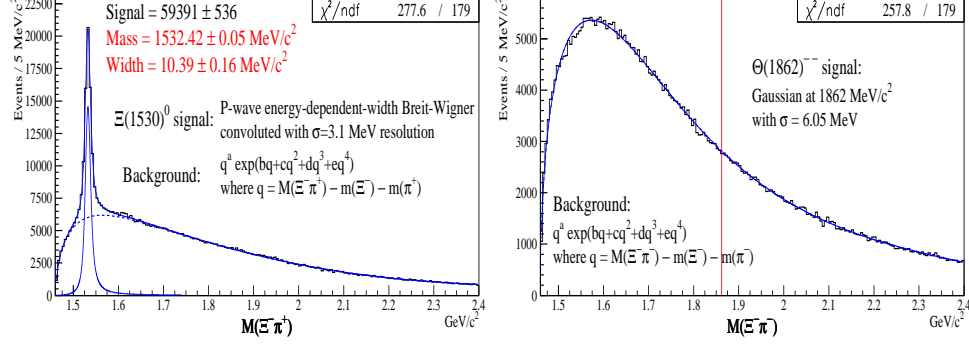
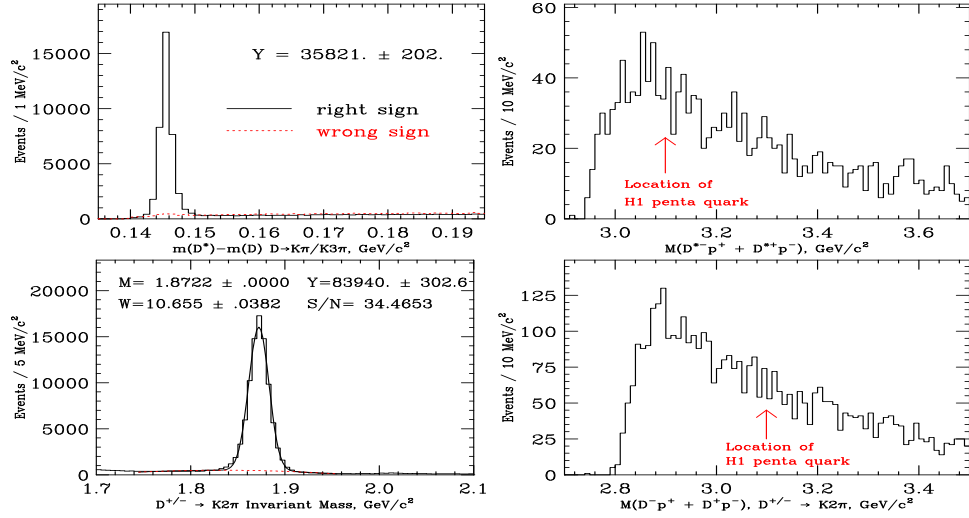
signal events. No pentaquark evidence is seen in the the  $pK_S^0$  mass plot (Fig. 1). We obtain 95% CL limits on the yield by determining how much the fitted yield must be increased to change the log-likelihood by 1.92 (continually minimizing the background parameters). This procedure is performed with a Breit-Wigner width of 0 and 15 MeV/ $c^2$ , both with Gaussian resolution varying from 2.36–3.07 MeV/ $c^2$ . The maximum limit on the yield over the mass range 1.51–1.56 GeV/ $c^2$  is 754 (2252) for  $\Gamma$  of 0 (15) MeV/ $c^2$ . To set cross section limits we generate pentaquarks the same as  $\Sigma(1385)^+$ . Using PYTHIA production and FOCUS MC simulation of  $K^*(892)^-$ ,  $\Sigma(1385)^\pm$ , and  $\Theta(1540)^+$  events we convert the yield limits into cross section ratio limits. For  $1.51 < M < 1.56$  GeV/ $c^2$ , the 95% CL limit on the production of  $\Theta(1540)^+$  relative to combined  $\Sigma(1385)^+$  and  $\Sigma(1385)^-$  is 0.7% (2.1%) for  $\Gamma$  of 0 (15) MeV/ $c^2$ . Relative to  $K^*(892)^-$ , the limit is 0.06% (0.17%) for  $\Gamma$  of 0 (15) MeV/ $c^2$ . We account for all branching ratios and assume  $B(\Theta(1540)^+ \rightarrow pK_S^0) = 0.25$ .

### 3. Search for $\phi(1860)^{--} \rightarrow \Xi^- \pi^-$

FOCUS reconstruction of  $\Xi^- \rightarrow \Lambda^0 \pi^-$  is described in Ref. <sup>13</sup>. We select 800,000  $\Xi^-$  candidates of which 75% are signal. We search for  $\Xi(1530)^0 \rightarrow \Xi^- \pi^+$  and the  $S = -2$  pentaquark candidate  $\phi(1860)^{--} \rightarrow \Xi^- \pi^-$ . We require the production and  $\Xi^- \pi^\pm$  vertices have CL > 1% and separated by less than  $2\sigma$ . The pion candidate must have a Čerenkov signature consistent with a pion. We find  $59391 \pm 536$   $\Xi(1530)^0$  events and no evidence for  $\phi(1860)^{--}$  as shown in Fig. 2. The yield upper limit calculated at a mass of 1.862 GeV/ $c^2$  is 114 (170) for  $\Gamma$  of 0 (15) MeV/ $c^2$  with resolution  $\sigma = 6.05$  MeV/ $c^2$ . Assuming production like  $\Xi(1530)^0$  we find  $\frac{\sigma(\phi(1860)^{--}) \times B(\phi(1860)^{--} \rightarrow \Xi^- \pi^-)}{\sigma(\Xi(1530)^0)} < 0.25\% (0.37\%)$  at 95% CL for  $\Gamma$  of 0 (15) MeV/ $c^2$ .

### 4. Search for $\Theta_c(3099)^0 \rightarrow D^{(*)-} p$

Using standard FOCUS charm reconstruction techniques we obtain a clean sample of  $D^{*-} \rightarrow \bar{D}^0 \pi^-$  ( $\bar{D}^0 \rightarrow K^+ \pi^-$ ) events and  $D^- \rightarrow K^+ \pi^- \pi^-$  events (Fig. 3). Combining  $35821 \pm 202$   $D^{*-}$  and  $83940 \pm 303$   $D^-$  candidates with a positively identified proton we find no evidence for a charm pentaquark as shown in Fig. 3.

Fig. 2. Fits to  $M(\Xi^-\pi^+)$  (left) for  $\Xi(1530)^0$  and  $M(\Xi^-\pi^-)$  for  $\Theta(1862)^{--}$ .Fig. 3. We add a proton to the  $D^{*-}$  events and  $D^-$  events (left) to search for  $\Theta_c(3099)$  (right).

## References

1. T. Nakano *et al.* [LEPS Collaboration], Phys. Rev. Lett. **91**, 012002 (2003).
2. V. V. Barmin *et al.* [DIANA Collaboration], Phys. Atom. Nucl. **66**, 1715 (2003).
3. S. Stepanyan *et al.* [CLAS Collaboration], Phys. Rev. Lett. **91**, 252001 (2003).
4. J. Barth *et al.* [SAPHIR Collaboration], Phys. Lett. **B572**, 127 (2003).
5. A. E. Asratyan, *et al.*, Phys. Atom. Nucl. **67**, 682 (2004).
6. V. Kubarovsky *et al.* [CLAS Collaboration], Phys. Rev. Lett. **92**, 032001 (2004).
7. A. Airapetian *et al.* [HERMES Collaboration], Phys. Lett. **B585**, 213 (2004).
8. A. Aleev *et al.* [SVD Collaboration], arXiv:hep-ex/0401024
9. M. Abdel-Bary *et al.* [COSY-TOF Collaboration], Phys. Lett. **B595**, 127 (2004).
10. S. Chekanov *et al.* [ZEUS Collaboration], Phys. Lett. **B591**, 7 (2004)
11. C. Alt *et al.* [NA49 Collaboration], Phys. Rev. Lett. **92**, 042003 (2004).
12. A. Aktas *et al.* [H1 Collaboration], Phys. Lett. **B588**, 17 (2004).
13. J. M. Link *et al.* [FOCUS Collaboration], Nucl. Instrum. and Meth. **A484**, 174 (2002).